CLAIMS

1. A multi-layer piezoelectric element comprising:

a stack formed by stacking piezoelectric layers and internal electrodes alternately one on another; and

external electrodes formed on a first side face and on a second side face of the stack, one of the adjacent internal electrodes being connected to the external electrode on the first side face and the other internal electrode being connected to the external electrode formed on the second side face,

wherein a ratio of change in the amount of displacement of the element after undergoing continuous operation of 1×10^9 cycles or more to an initial device displacement before undergoing continuous operation is not larger than 5%.

2. A multi-layer piezoelectric element comprising:

a stack formed by stacking piezoelectric layers and internal electrodes alternately one on another; and

external electrodes formed on a first side face and on a second side face of the stack, one of the adjacent internal electrodes being connected to the external electrode on the first side face and the other internal electrode being connected to the external electrode formed on the second side face,

wherein a ratio of change in the resistance of the

element after undergoing continuous operation of 1×10^9 cycles or more to an initial of resistance before undergoing continuous operation is not larger than 5%.

3. The multi-layer piezoelectric element according to claims 1 or 2,

wherein a maximum change in the amount of displacement of the element during continuous operation is not larger than 5%.

4. The multi-layer piezoelectric element according to claims 1 or 2,

wherein a ratio of change in thickness of the piezoelectric layer after undergoing continuous operation of 1×10^9 cycles or more to the thickness of the piezoelectric layer before the continuous operation is not larger than 5%.

5. The multi-layer piezoelectric element according to claims 1 or 2,

wherein a maximum change in resistance of the element during continuous operation is not larger than 5%.

6. A multi-layer piezoelectric element comprising:

a stack formed by stacking piezoelectric layers and internal electrodes alternately one on another; and

external electrodes formed on a first side face and on a second side face of the stack, one of the adjacent internal electrodes being connected to the external electrode on the first side face and the other internal electrode being connected to the external electrode formed on the second side face,

wherein pillars are provided to penetrate the internal electrode and connect the piezoelectric layers that oppose each other via the internal electrode.

7. The multi-layer piezoelectric element according to claim 6,

wherein not less than 30% of the pillars have diameter in the section thereof joined with the piezoelectric layer not smaller than 50% of the maximum diameter of the pillars.

8. The multi-layer piezoelectric element according to claims 6 or 7,

wherein mean value of minimum diameters of the pillars is not smaller than 0.2 μm.

9. The multi-layer piezoelectric element as in one of claims 6-8,

wherein a number of pillars per 1 mm is from 5 to 150.

10. The multi-layer piezoelectric element as in one of claims 6-9,

wherein a difference in thermal expansion coefficient between the pillar and the piezoelectric material that constitutes the piezoelectric layers is $3 \times 10^{-5}/°C$ or less.

11. The multi-layer piezoelectric element as in one of claims 6-10,

wherein the pillars are formed from the same material of the piezoelectric material.

12. The multi-layer piezoelectric element as in one of claims 1-11,

wherein the stack includes inactive protective layers formed by alternately stacking the piezoelectric layers and dummy layers on the top and bottom thereof, and the ratio A/B of minimum distance A between the periphery of the dummy layer and the side face of the inactive protective layers to width B of the inactive protective layer is in a range from 0.01 to 0.08.

13. The multi-layer piezoelectric element according to claim 12,

wherein the dummy layer contains a metal.

14. The multi-layer piezoelectric element according to claims 12 or 13,

wherein the dummy layer is formed from the same material of the internal electrode.

15. The multi-layer piezoelectric element as in one of claims 12-14,

wherein the piezoelectric layer has a thickness not less than 50 μm.

16. The multi-layer piezoelectric element as in one of claims 12-15,

wherein the dummy layer contains an inorganic composition selected from a group consisting of a metal oxide, a nitride and a carbide.

17. The multi-layer piezoelectric element as in one of claims 12-16,

wherein the dummy layer contains 2% by weight or more of an inorganic composition.

18. The multi-layer piezoelectric element as in one of claims 1-17,

wherein the metal composition in the internal electrode contains a group VIII metal and/or a group Ib metal as the

main component.

19. The multi-layer piezoelectric element according to claim 18,

wherein a proportion M1 (% by weight) of the group VIII metal and a proportion M2 (% by weight) of the group Ib metal in the internal electrode satisfy the relations $0 < M1 \leq 15$, $85 \leq M2 < 100$ and $M1 + M2 = 100$.

20. The multi-layer piezoelectric element according to claims 18 or 19,

wherein the group VIII metal is at least one kind selected from a group consisting of Ni, Pt, Pd, Rh, Ir, Ru and Os, and the group Ib metal is at least one kind selected from a group consisting of Cu, Ag and Au.

21. The multi-layer piezoelectric element as in one of claims 18-20,

wherein the group VIII metal is at least one kind selected from a group consisting of Pt and Pd, and the group Ib metal is at least one kind selected from a group consisting of Ag and Au.

22. The multi-layer piezoelectric element as in one of claims 18-20,

wherein the group VIII metal is Ni.

23. The multi-layer piezoelectric element as in one of claims 18-20,

wherein the group Ib metal is Cu.

24. The multi-layer piezoelectric element as in one of claims 1-23,

wherein an oxide and one of a nitride and a carbide are added to the internal electrode along with the metal composition.

25. The multi-layer piezoelectric element according to claim 24,

wherein the oxide contains perovskite type oxide consisting of $PbZrO_3$-$PbTiO_3$ as the main component.

26. The multi-layer piezoelectric element as in one of claims 1-25,

wherein the piezoelectric layers contain perovskite type oxide as the main component.

27. The multi-layer piezoelectric element according to claim 26,

wherein the piezoelectric layers contain perovskite type

oxide consisting of $PbZrO_3$-$PbTiO_3$ as the main component.

28. The multi-layer piezoelectric element as in one of claims 1-27,

wherein a firing temperature of the stack is not less than 900 nor more than 1000°C.

29. The multi-layer piezoelectric element as in one of claims 1-25,

wherein a deviation in the composition of the internal electrode that is caused by the firing operation is not larger than 5%.

30. The multi-layer piezoelectric element as in one of claims 1-29,

wherein a groove is formed between the end of the other internal electrode and the external electrode on the first side face, with the groove being filled with an insulating material and a groove is formed between the end of the one internal electrode and the external electrode on the second side face, with the groove being filled with an insulating material, the insulating material having Young's modulus lower than that of the piezoelectric layer.

31. The multi-layer piezoelectric element as in one of

claims 1-30,

wherein the internal electrode includes voids and the voids occupy 5 to 70% of cross sectional area of the internal electrode.